Decoding Complex Hand Movements Using High Density ECoG and High Field fMRI

M. G. Bleichner[1], J. M. Jansma[1], Z. V. Freudenburg[1], E. J. Aarnoutse[1], M. J. Vansteensel[1], N. F. Ramsey[1]

[1]*Rudolf Magnus Institute of Neuroscience, Dept. of Neurology and Neurosurgery, University Medical Center Utrecht, The Netherlands*

Correspondence: N. F. Ramsey, Universitair Medisch Centrum Utrecht, Heidelberglaan 100, Huispost: G03.124, 3584 CX Utrecht, The Netherlands. E-mail: n.f.ramsey@umcutrecht.nl

Abstract. Implantable brain computer interfaces promise to provide communication for severely paralyzed people. Current solutions focus either on high-dimensional control of a robot arm, or on a single-channel switch or click. We here investigate feasibility of decoding multiple classes from the same patch of cortex, to enable some form of speech. For this it is necessary to identify multiple neuronal states that can be decoded reliably. We postulate that inner sign-language can offer a solution. To test this, we evaluted decodability of representation of complex hand movements in the primary sensorimotor cortex using high field fMRI and high density ECoG. Using simple template matching classification, four hand gestures were classified with up to 100% accuracy with both techniques. Our studies indicate that complex hand gestures exhibit reliable and discriminable spatial representations on sensorimotor cortex which makes them a promising candidate for speech-oriented BCIs.

Keywords: ECoG, fMRI, hand movements, decoding

1. Introduction

Completely implantable and minimally invasive brain computer interfaces (BCI) promise to provide severely paralyzed patients with the ability to communicate independently of their caregivers. In the ideal case these BCIs would allow for reliable, fast, and effortless communication. Therefore, it is necessary to identify brain signals which are easily detected and recognized by a classifier and which can be intuitively generated by the user for use as a control signal. Hand gestures as they are used in finger spelling in sign languages appear to be a promising candidate. The entire alphabet can be represented in form of single hand gestures. The detailed topographic representation [Penfield et al., 1937] and the plasticity of the primary motor cortex (M1) make it likely that each gesture exhibits a reliable and specific representation that can be identified. In this study we therefore map out the neuronal representations of complex hand movements on the motor cortex using ECoG and fMRI. ECoG provides high fidelity signals, with very good temporal resolution. The disadvantage is a sparse sampling of the cortex. fMRI on the other hand provides a complete sampling of the entire cortex and allows studying larger populations of participants, albeit at a low temporal resolution. Those two methods complement each other and can provide detailed insight in the representation of the underlying processes.

2. Material and Methods

The execution of four hand gestures, taken from the American Sign Language alphabet (corresponding to the letters ‘F’,’L’, ‘W’ and ‘Y’), was studied with high density ECoG in epilepsy patients and high field fMRI (7T) in healthy volunteers. To control for the correct execution of the task the actual hand movements were recorded using a 5DT data glove, allowing measuring the movements of the individual fingers.

2.1. High field fMRI

Twelve healthy volunteers (4 male, age 25.78 ± 5.8 years) participated in the fMRI study. They performed two event related sessions; the first one was used as training set the second as test set. The training session consisted of 256 trials (32 trials for each of the 4 movements) and 128 rest trials with a variable inter trial interval (2.6 s-18.2 s). Timing of stimuli was based on interleaved m-sequences to optimize statistical efficiency [Buracas et al., 2002]. The slow event related design included 40 trials (10 for each movement) with a fixed inter stimulus interval of 13 s, this assured that the effects of the previous trial were washed out. Each stimulus was presented for 750 ms. During the inter-trial interval a fixation cross was shown. The fMRI measurements were implemented using a 7 T Philips Achieva MRI system with a 32-channel head-coil. The functional data was recorded using an EPI sequence. The field of view covered the left pre- and postcentral gyrus. During the training and the test session 535 volumes and

481 volumes, were made, respectively. A high-resolution image was acquired for anatomical reference using a T1 weighted 3D TFE sequence. The data was slice time corrected, realigned, and detrended. The feature selection was based on the training set; voxels that showed task related activity for one of the conditions were selected. As features the sum of the estimated fMRI response, as estimated by a standard FIR analysis, of each voxel and each trial at the 4th 5th and 6th scan after stimulus onset was used. For the test session the raw fMRI signal was used.

2.2. High density ECoG

From 5 patients, undergoing neurosurgery for epilepsy, multi-channel subdural ECoG data was recorded. High-density grids were implanted (32-64 contact points, 1.3 mm exposed surface, inter-electrode distance 3 mm center to center) beside the standard macro grid electrodes and were left in place for one week. In all patients part of M1 as well as S1 were covered around the superior aspect of the primary motor cortex, where hand function could be expected. Each gesture was presented 10 times, providing 40 trials in total. The data was band passed filtered to remove the 50 Hz line noise. Channels containing artifacts were removed. All channels were re-referenced to the common average reference for all included electrodes on the grid. The data was epoched into segments of 2 s before and 3 s after movement onset (based on the data glove readings). The power in the frequency range 65-95 Hz was computed for all epochs using a wavelet transform (Gabor wavelet, 7 cycles). The average power per channel between 1 s before movement onset and 2 s after movement onset were used as features.

2.3. Classification

For classification of the movements, a 'nearest-neighbor' classification procedure was applied [Pereira et al., 2009] for ECoG and fMRI. Individual trials were classified by computing the Pearson correlation between the trial and four templates. The templates consisted of the average response for all remaining trials within the four conditions; for the fMRI the average response was based on the training session for ECoG it was based on a leave-one-out procedure. The trial was classified as the gesture type it had the highest correlation with in a winner-takes-all manner.

3. Results

For the fMRI the average classification accuracy for the gestures was 72% (sem 4.25, chance level 25%) with a range over participants from 49% to 100%. The most informative areas for the classification were located in a confined region in the hand knob area on the primary motor cortex and the adjacent sensory cortex on the postcentral gyrus. The variations in classification accuracy between participants could be explained by variations in the fMRI signals of individual trials, which in turn could be explained by variations in the consistency of executing the gestures. For the ECoG the average classification accuracy was 65% (sem 8.8, chance level 25%) with a range over participants from 47% to 97%. The variations in classification accuracy between participants could be explained by the position of the grid (different part of the hand region were covered in different participants).

4. Discussion

Our studies indicate that complex hand gestures exhibit reliable and discriminable spatial representations on sensorimotor cortex. These representations can be used to classify gestures with high accuracy, using only a confined unilateral area of the brain. Differences in classification accuracy between participants were related to differences in task performance (fMRI) and grid location (ECoG). A simple ‘nearest neighbor’ classification procedure made it possible to classify both ECoG and fMRI data with high accuracy. For both methods the most informative regions were in the hand region of sensorimotor cortex. Our results suggest that high field fMRI can be used prior to implantation to identify the target area for high-density ECoG electrode grids. We conclude that complex hand gestures are a promising control signal for future multi-mode BCIs. Future work has to show how many gestures can be differentiated and whether imagined movements can be decoded in a similar fashion.

References

Buracas, GT. Efficient design of event-related fMRI experiments using M-sequences. *Neuroimage*, 16:801-13, 2002.

Penfield, Somatic motor and sensory representation in the cerebral cortex of man as studied by electrical stimulation. *Brain,* 37:389-443, 1937.

Pereira, F. Machine learning classifiers and fMRI: a tutorial overview. *Neuroimage,* 45:199-209, 2009.